



channels 20 is then checked by external circuitry 6 against the test signal to determine whether the transceiver is functioning properly.

5                    During the course of transmission from the multiplexer 14 through the clock/data recovery circuit 10 to the demultiplexer 12, it is not unusual to have a collective shift in the test signal causing the relative position of the entire test signal to change without affecting the integrity of the test signal. In other words, the beginning of the test signal frame which is transmitted via one input channel of the multiplexer 14 may not always come out at precisely the corresponding output channel of the demultiplexer 12. For example, the beginning of the test signal frame transmitted via the first multiplexer input channel may not come out at the corresponding first demultiplexer output channel. Thus, while the contents or bits within the frame may have been transmitted correctly, a shift in the frame position may lead to an erroneous conclusion that the transceiver is malfunctioning. In order to avoid this situation, a "framer" circuit, which is commonly known in the art, is typically employed to accurately align or "frame" the initial test signal and the output received from the demultiplexer 12 before the two signals are compared.

20                    Framer circuits that must keep track of signal timing for alignment purposes tend to be quite complex. Due to their complexity, such circuits are relatively expensive. Furthermore, such circuits typically occupy large silicon area and consume a relatively large amount of power rendering it difficult to have such circuit incorporated with a transceiver in an integrated circuit. Therefore, it would be desirable to provide a method and device for implementing a built-in self-test for multi-channel transceivers which is cost effective and capable of being integrated with a transceiver in an integrated circuit.

## SUMMARY OF THE INVENTION

30                    A method and device for testing multi-channel transceivers in an integrated circuit is provided. More specifically, the present invention relates to a method and device for implementing a built-in self-test for multi-channel transceivers. The present invention includes a test pattern generator, a multiplexer, a demultiplexer, and a test result evaluator. The test pattern generator generates a test pattern which is fed into each of the input channels of the multiplexer. In an exemplary embodiment, the test

pattern generator is implemented using a linear feedback shift register. The linear feedback shift register is made to cycle through its various states and its parallel output is used to form a pseudo-random test pattern. This test pattern is uniquely represented by a signature which can be used later on to determine whether the transceiver is functioning properly.

The test pattern is fed to all the input channels of the multiplexer. The multiplexer multiplexes the data from all its input channels and then relays the data to the demultiplexer. The test result evaluator then individually checks the data at each of the output channels of the demultiplexer to determine whether the data received at each output channel is the same as the test pattern.

In order to facilitate the checking process, signature analysis is utilized. The test result evaluator first records the data stream coming out of each output channel of the demultiplexer at the appropriate time. The recording is initiated when a specific bit sequence is detected. The corresponding signature for the recorded data stream is then obtained. In an exemplary embodiment, a linear feedback shift register can be used to obtain the corresponding signature. Once the corresponding signature is obtained, it is compared to the signature of the test pattern. The comparison result then indicates whether each channel of the transceiver is working properly.

Reference to the remaining portions of the specification, including the drawings and claims, will realize other features and advantages of the present invention. Further features and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with respect to accompanying drawings, like reference numbers indicate identical or functionally similar elements.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a simplified circuit block diagram showing a conventional testing configuration used to test the operation accuracy of a transceiver;

Fig. 2 is a simplified circuit block diagram showing one embodiment of the present invention;

Fig. 3 is a simplified circuit block diagram showing one embodiment of the test pattern generator in accordance with the present invention;

Fig. 4 is a simplified circuit block diagram showing one embodiment of the test result evaluator in accordance with the present invention;

Fig. 5 is a simplified circuit block diagram showing one embodiment of the signature analyzer in accordance with the present invention; and

Fig. 6 is a simplified circuit block diagram showing one embodiment of a reset circuit capable of resetting the signature recorder in accordance with the present invention.

#### DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The present invention will now be described in greater detail in connection with specific embodiments. Fig. 2 is a simplified circuit block diagram showing one embodiment of the present invention. This embodiment of the present invention includes a test pattern generator (TPG) 22, a multiplexer (MUX) 14, a clock/data recovery (CDR) circuit 10, a demultiplexer (DEMUX) 12 and a test result evaluator (TRE) 24.

As Fig. 2 shows, the TPG 22 is coupled to the MUX 14 via an input selector 26. The input selector 26 controls the type of signal (data or test signal) that is to be made available to the MUX 14. During testing mode, output from the TPG 22 is fed to the MUX 14 via the input selector 26 to allow testing to be performed. The TPG 22 is responsible for generating a test signal having a unique pattern that can be used as an input to the MUX 14. The MUX 14, in turn, is coupled to the CDR 10. Since the MUX 14 outputs its data at a high rate, it is desirable to have the CDR 10 receive the data from the MUX 14 so as to allow the data to be recovered. The CDR 10 then provides the recovered data as input to the DEMUX 12. The DEMUX 12 then feeds the recovered data into the TRE 24 for evaluation.

The general operation of the embodiment of the present invention as shown in Fig. 2 is now described in further details. The TPG 22 generates a pseudo-random test pattern which is fed into each input channel of the MUX 14. In an exemplary embodiment, the MUX 14 shown in Fig. 2 has sixteen (16) input channels and the pseudo-random test pattern generated by the TPG 22 is fed into each of these sixteen (16) input channels. The pseudo-random test pattern is then transmitted by the MUX 14 to the

CDR 10 which, in turn, forwards the test pattern to the DEMUX 12. Output from each of the DEMUX output channels is then directed to the TRE 24 for evaluation to determine whether the test pattern generated by the TPG 22 is the same as that received at each of the DEMUX output channels. A match between the signal at an output channel of the DEMUX 12 and the test pattern generated by the TPG 22 indicates that the transceiver is performing its functions properly. By transmitting the same test pattern over the MUX input channels, each DEMUX output channel can be tested individually without the need to align or "frame" data from other DEMUX output channels.

In one embodiment, the TPG 22, whose primary function is to generate the pseudo-random test pattern, is implemented using a linear feedback shift register. A linear feedback shift register is an example of a general linear finite state machine, where the memory cells are made up of, e.g., D flip-flops and the next state operations are implemented using XOR logic functions. A linear feedback shift register of length  $n$  can be described by a polynomial with binary coefficients of up to degree  $n$ , where the nonzero coefficients of the polynomial denote the positions of the respective feedback connections. If the linear feedback shift register is initialized to a nonzero state, it cycles through a sequence of states and eventually comes back to the initial state in accordance with the next-state rules implemented by its polynomial description. The structure and function of a linear feedback shift register is commonly known in the art. By manipulating the parallel output of the linear feedback shift register, which will be explained further below, it is possible to generate a pseudo-random bit stream which can be used as a test pattern. Due to the specific polynomial description of a linear feedback shift register, a specific signature can be identified which uniquely corresponds to the pseudo-random bit stream.

In an exemplary embodiment as shown in Fig. 3 in accordance with the present invention, the linear feedback shift register 30 is 8-bit long. The pseudo-random test pattern that can be generated by the 8-bit linear feedback shift register 30 is as follows. By its nature of operation which is well-known in the art, the 8-bit linear feedback shift register 30 is capable of producing  $2^8 - 1$ , i.e., 255 nonzero states. Since the linear feedback shift register 30 is 8-bit long, its parallel output which represents a state at any particular instant is also 8-bit long. By duplicating the 8-bit parallel output and then concatenating the two 8-bit parallel outputs, a 16-bit sequence can be used as

parallel input to the sixteen (16) input channels of the MUX 14. Preferably, the two 8-bit parallel outputs are concatenated and fed into the MUX 14 in such a way so as to minimize the possibility that two input channels which are multiplexed together have the same data. This is done to obtain a better test pattern for testing. Since the 8-bit linear feedback shift register 30 cycles through 255 nonzero states, a pseudo-random serial bit stream which repeats itself once every 255 bits is generated for each of the MUX input channels. In other words, a pseudo-random bit stream which is 255-bit long can be used as the test pattern.

Since an 8-bit linear feedback shift register 30 represents a polynomial with binary coefficients up to the 8<sup>th</sup> degree, an 8-bit signature which uniquely corresponds to the 255-bit pseudo-random bit stream can be generated. It should be noted that by generating the test pattern for each MUX input channel in the manner described above, the same 8-bit signature corresponds to all the pseudo-random bit streams inputted into the MUX input channels. The generation of this 8-bit signature is commonly known in the art. By using this 8-bit signature as opposed to a 255-bit bit stream and using the same 8-bit signature to test the signals at all the DEMUX output channels, the cost of evaluating the DEMUX outputs can be significantly reduced.

It should be understood that the linear feedback shift register is merely an illustrative example and that a person of ordinary skill in the art will know of other ways and methods to implement circuitry or other logic functions that are capable of generating a pseudo-random bit stream that can be used as a test pattern.

As mentioned above, the test pattern is then transmitted via the MUX 14 and DEMUX 12 to the TRE 24. The TRE 24 examines the output received from the DEMUX 12 to determine whether it is the same as the test pattern initially generated by the TPG 22. Fig. 4 is a simplified block circuit diagram showing one embodiment of the TRE in accordance with the present invention. In this embodiment, the TRE 24 is made up of a signature analyzer 40, an AND logic function 42, and a flip-flop 44. The output channels of the DEMUX 12 are coupled to the signature analyzer 40. The outputs of the signature analyzer 40 are coupled to the AND logic function 42 which, in turn, is coupled to the flip-flop 44.

The TRE 24 generally operates in the following manner. The signature analyzer 40, which will be described in further detail below, serves to check the signature of the bit stream received from each of the DEMUX output channels. The bit stream from each of the DEMUX output channels is examined individually to determine whether it corresponds to the signature specific to the test pattern generated by the TPG 22. The results produced by the signature analyzer 40 are then fed into the AND logic function 42. The AND logic function 42 provides a compare function. By the nature of operation of the AND logic function 42, any non-uniformity amongst its inputs can be detected and then used to signify an exception condition. For example, if a high signal or logic "1" is used to indicate that there is a match between the bit stream of a DEMUX output channel and the test pattern, then a low signal or logic "0" produced by the AND logic function 42 would indicate that there is a mismatch or error amongst one or more of the DEMUX output channels. The result of the AND logic function 42 is then recorded for any future use using the flip-flop 44. Those skilled in the art appreciate that other logic functions, such as exclusive OR and the like can be employed to perform the compare function.

Fig. 5 is a simplified circuit block diagram showing an exemplary embodiment of the signature analyzer 40 in accordance with the present invention. In this embodiment, the signature analyzer 40 is made up of three components, namely, a signature recorder controller 50, a signature recorder 52, and a signature comparator 54. As shown in Fig. 5, these three components are coupled to one another in a serial manner.

As its name implies, the main function of the signature recorder controller 50 is to control the operation of the signature recorder 52. More specifically, the signature recorder controller 50 controls when to record the bit stream coming from the DEMUX output channel and analyze the corresponding signature. In the case of using an 8-bit linear feedback shift register 30 as the TPG 22 to produce a test pattern, the signature recorder controller 50 controls when to record the 255-bit bit stream coming from a DEMUX output channel. To pinpoint the precise moment to start to record the bit stream received from a DEMUX output channel, the signature recorder controller 50 continually examines the bit stream looking for a unique bit sequence within the bit stream. For example, in the case of a 255-bit test pattern generated by an 8-bit linear feedback shift register 30, there is a unique bit sequence of seven consecutive 1's within the 255-bit test pattern. By identifying the unique sequence of seven consecutive 1's, the

signature recorder controller 50 is able to precisely control the activation of the signature recorder 52 to record the appropriate bit stream.

Upon activation, the signature recorder 52 records the appropriate bit stream from a DEMUX output channel and generates a unique signature for that bit stream. In an exemplary embodiment, a linear feedback shift register can be used to implement the signature recorder 52. It should be noted that, given a bit stream which is identical to the test pattern, the signature recorder 52 must be able to generate a signature which is identical to the signature of the test pattern generated by the TPG 22 to permit any meaningful evaluation. For example, the signature recorder 52 can be an 8-bit linear feedback shift register. By serially feeding the 255-bit bit stream into the 8-bit linear feedback shift register, a unique signature, in form of a 8-bit bit pattern, for that particular 255-bit bit stream can be produced at the parallel output of the 8-bit linear feedback shift register.

Once the corresponding signature for the bit stream received from the DEMUX output channel is obtained by the signature recorder 52, it is then fed into the signature comparator 54 for comparison. The signature comparator 54 has available to it the unique signature of the test pattern originally generated by the TPG 22. The signature comparator 54 can then compare the unique signature of the test pattern to the corresponding signature produced by the signature recorder 52.

Since the bit stream from the DEMUX output channel is fed into the signature recorder 52 in a serial manner, i.e., one bit at a time, the signature recorder 52 does not produce the correct representative signature for the entire bit stream until all the bits in the bit stream have been read by the signature recorder 52. Hence, the signature comparator 54 only generates a meaningful result at periodic intervals. For the case of a 255-bit bit stream, the output of the signature comparator 54 only represents a meaningful comparison result every time 255 bits have been read by the signature recorder 52.

Since the output of the signature comparator 54 does not always represent a meaningful result, such output need to be examined at the precise moment. A flip-flop 60 can be used to record the output of the signature comparator 54 at the desired time. For example, the flip-flop 60 can record the output of the signature comparator 54 every



255 bits. The flip-flop 60 can then output the result it recorded to the AND logic function 42.  
 5        After the output of the signature comparator 54 has been recorded, the signature recorder 52  
 can be reset for the next test cycle. Fig 6 is a simplified circuit block diagram showing one  
 embodiment of a reset circuit configured to reset the signature recorder 52 in accordance with  
 the present invention. Based on the teaching and disclosure provided in Fig. 6, a person of  
 ordinary skill in the art will appreciate the operations of the reset circuit. As can be seen  
 10        from Fig. 6, when an error condition represented by signal "CHFLG" and received from the  
 signature comparator 54 is present, the signature recorder 52 is not reset; otherwise, the  
 signature recorder 52 is reset periodically.

15        While the signature analyzer 40, and its components thereof, have been described  
 above with respect to a single DEMUX output channel, it should be understood that the  
 signature analyzer 40 is capable of concurrently handling multiple bit streams emanating  
 from the DEMUX output channels.

20        It should be further understood that the present invention as described above is  
 capable of being implemented in an integrated circuit with other transceiver circuitry. The  
 advantage of having the present invention integrated with other transceiver circuitry is that it  
 provides a built-in self-test for a multi-channel transceiver. Such self-testing functionality  
 eliminates the need for external testing equipment and further provides an efficient method to  
 identify any problems within the integrated circuit.

25        It is understood that the examples and embodiments described herein are for  
 illustrative purposes only and that various modifications or changes in light thereof will be  
 suggested to persons skilled in the art and are to be included within the spirit and purview of  
 this application and scope of the appended claims. All publications, patents, and patent  
 30        applications cited herein are hereby incorporated by reference for all purposes in their  
 entirety.